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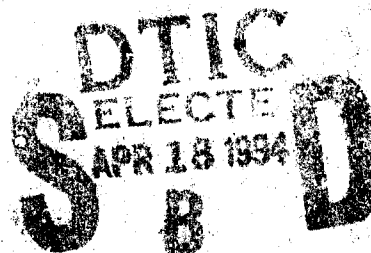
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HALON 1211 REPLACEMENT AGENT
EVALUATION - PERFLUOROHXANE
AND HALOTRON I

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NOVEMBER 1993

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Final Report for March 1993 - November 1993

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This technical report has been reviewed and is approved for publication.



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PREFACE

This report was prepared by Applied Research Associates, Inc., Bldg. 1142, Tyndall Air Force Base, Florida 32403, for the Wright Laboratory, Air Base Systems Branch, Fire Protection & Crash Rescue Systems Section (WL/FIVCF), 139 Barnes Drive, Suite 2, Tyndall Air Force Base, Florida 32403-5323. The work was accomplished under Scientific and Engineering Technical Assistance (SETA) contract number F08635-93-C-0020.

This test program was requested and funded by the Federal Aviation Administration (FAA), Fire Safety Branch, Atlantic City International Airport, Atlantic City, New Jersey 08405. Testing was conducted between 24 March and 2 November 1993 at Tyndall Air Force Base, Florida. The FAA project officer was Mr. Joseph A. Wright. The WL/FIVCF project officer was Mr. Charles W. Risinger. The Halotron I® fire extinguishing agent was provided at no cost by American Pacific Corporation.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this test program was to compare the fire-extinguishing performance of perfluorohexane and Halotron I[®], relative to Halon 1211; for the extinguishment of pool and three-dimensional flowing fuel fires. This research was requested and funded by the Federal Aviation Administration (FAA) Fire Safety Branch.

B. BACKGROUND

Halon 1211 is a very effective, "clean" fire-extinguishing agent. The National Fire Protection Association (NFPA) defines a "clean agent" as an electrically nonconductive, volatile or gaseous fire extinguishing agent that does not leave a residue upon evaporation. Halon 1211 represents the first line of defense for aircraft maintenance personnel confronted with small fires on or around aircraft. However, Halon 1211 depletes stratospheric ozone, and its production will be banned by January 1994, as specified by the November 1992 Copenhagen Amendments to the Montreal Protocol.

Perfluorohexane and Halotron I are two candidate clean replacement agents for Halon 1211. Both agents have been approved by the U.S. Environmental Protection Agency's (EPA) Significant New Alternatives Policy (SNAP) program for flight line use. Halotron I, also known as HCFC Blend B, is a blend of HCFC-123 and two gases.

C. SCOPE

This test program quantified the fire extinguishment performance of the candidate Halon 1211 replacement agents, perfluorohexane and Halotron I. Both of these agents were tested head-to-head with Halon 1211 for several typical aircraft fire scenarios. The following tests were conducted: agent throw-range tests, dry-pool fire extinguishment tests, three-dimensional inclined-plane running-fuel fire tests, simulated engine-nacelle running-fuel fire tests, and simulated wheel-well fires involving hydraulic fluid. All tests except the wheel-well fire used JP-4 as the fuel. Amerex Model 600 (150-pound wheeled) extinguishers were used to dispense the agent in each test.

Initially, all three agents were dispensed using standard Amerex Model 600 extinguishers. However, it became apparent early in the testing that the standard Amerex extinguisher was not the optimum system for dispensing Halotron I. Despite following precise extinguisher loading procedures, a smooth, continuous flow of agent could not be achieved throughout the entire duration of discharge. It was concluded that the pulsating flow was due mainly to the drop in extinguisher pressure during discharge.

Based on the hypothesis that Halotron I performance would be improved if a constant agent discharge rate could be achieved, American Pacific Corporation (AMPAC) developed a modification to the Amerex Model 600 extinguisher. The modification basically consisted of the addition of a booster cylinder filled with Halotron I expander gas. The purpose of the additional

expander gas was to maintain a constant extinguisher operating pressure. At the request of the FAA, additional Halotron I testing (using modified extinguishers) was conducted.

Through a contract with the Amerex Corporation, AMPAC further optimized their modified extinguisher design. At the request of the FAA, this extinguisher configuration was also tested.

D. CONCLUSIONS

When using standard Amerex Model 600 extinguishers to dispense each agent, Halotron I proved to be slightly more effective than perfluorohexane for extinguishing the five fire scenarios tested during this project. Halotron I was nearly twice as effective as perfluorohexane for extinguishing the inclined-plane running-fuel fires; and 50 percent more effective than perfluorohexane for extinguishing the wheel-well hydraulic fluid fires. Both agents exhibited equal performance on the dry-pool fires and the engine-nacelle running-fuel fires. Perfluorohexane outperformed Halotron I in the effective throw-range testing.

Performance of the Halotron I system was improved by optimizing the Amerex extinguisher with an expander gas booster cylinder. The magnitude of the improvement was not quantified since the optimized extinguisher was not tested against the original fire test scenarios. Using the optimized extinguisher, the "chugging" problem was eliminated, and the agent discharge rate was increased by 36 percent. Additionally, the throw-range was improved (based on visual observation), and the agent capacity of the extinguisher was increased from 130 pounds to 180 pounds.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this test program was to compare the fire-extinguishing performance of perfluorohexane and Halotron I[®], relative to Halon 1211; for the extinguishment of pool and three-dimensional flowing fuel fires. This research was requested and funded by the Federal Aviation Administration (FAA) Fire Safety Branch.

B. BACKGROUND

Halon 1211 is a very effective, "clean" fire-extinguishing agent. The National Fire Protection Association (NFPA) defines a "clean agent" as an electrically nonconductive, volatile or gaseous fire extinguishing agent that does not leave a residue upon evaporation. Halon 1211 represents the first line of defense for aircraft maintenance personnel confronted with small fires on or around aircraft. However, Halon 1211 depletes stratospheric ozone, and its production will be banned by January 1994, as specified by the November 1992 Copenhagen Amendments to the Montreal Protocol.

Perfluorohexane and Halotron I are two candidate clean replacement agents for Halon 1211. Both agents have been approved by the U.S. Environmental Protection Agency's (EPA) Significant New Alternatives Policy (SNAP) program for flight line use. Halotron I, also known as HCFC Blend B, is a blend of HCFC-123 and two gases. Table 1 presents selected physical properties, as well as the Ozone Depletion Potential and the Acute Toxicity of Halon 1211, perfluorohexane, and Halotron I.

C. SCOPE

This test program quantified the fire extinguishment performance of the candidate Halon 1211 replacement agents, perfluorohexane and Halotron I. Both of these agents were tested head-to-head with Halon 1211 for several typical aircraft fire scenarios. The following tests were conducted: agent throw-range tests, dry-pool fire extinguishment tests, three-dimensional inclined-plane running-fuel fire tests, simulated engine-nacelle running-fuel fire tests, and simulated wheel-well fires involving hydraulic fluid. All tests except the wheel-well fire used JP-4 as the fuel. Amerex Model 600 (150-pound wheeled) extinguishers were used to dispense the agent in each test.

Initially, all three agents were dispensed using standard Amerex Model 600 extinguishers. However, it became apparent early in the testing that the standard Amerex extinguisher was not the optimum system for dispensing Halotron I. Despite following precise extinguisher loading procedures, a smooth, continuous flow of agent could not be achieved throughout the entire duration of discharge. It was concluded that the pulsating flow was due mainly to the drop in extinguisher pressure during discharge.

TABLE 1. FIRE-EXTINGUISHING AGENT PROPERTY COMPARISON

Property	Halon 1211	perfluorohexane	Halotron I
Chemical Formula	CF ₂ ClBr	C ₆ F ₁₄	C ₂ HCl ₂ F ₃ + (exp)
Molecular Weight	165.4	338	150.7
Boiling Point	-4°C	56°C	27°C *
Liquid Density at 25°C	1.79 kg/l	1.68 kg/l	1.48 kg/l
Vapor Pressure at 25°C	2.67 bar	0.31 bar	15.49 bar **
Atmospheric Lifetime ***	12.5 - 25 yrs.	500 - 1000 yrs.	3.5 - 11 yrs.
Ozone Depletion Potential (ODP)	4	0	0.014
Acute Toxicity, ALC, LC ₅₀ (4 hrs.)	3.1 - 10%	> 30%	> 3%
<p>* For blend at 1 atm., 70% filling ratio, 1 kg/l filling density</p> <p>** Vapor pressure for blend and expander gas</p> <p>*** Depending on model used for calculation</p>			

Based on the hypothesis that Halotron I performance would be improved if a constant agent discharge rate could be achieved, American Pacific Corporation (AMPAC) developed a modification to the Amerex Model 600 extinguisher. The modification basically consisted of the addition of a booster cylinder filled with Halotron I expander gas. The purpose of the additional expander gas was to maintain a constant extinguisher operating pressure. At the request of the FAA, additional Halotron I testing (using modified extinguishers) was conducted.

Through a contract with the Amerex Corporation, AMPAC further optimized their modified extinguisher design. At the request of the FAA, this extinguisher configuration was also tested.

SECTION II

TEST PROTOCOL

A. INTRODUCTION

Five unique fire extinguishment tests were utilized in this research program: agent throw-range tests, dry-pool fire extinguishment tests, three-dimensional inclined-plane running-fuel fire tests, simulated engine-nacelle running-fuel fire tests, and simulated wheel-well fires involving hydraulic fluid. The protocol for conducting each of these tests is detailed below.

B. AGENT THROW-RANGE TESTS

The agent-specific, effective throw-range of the Amerex Model 600 (150-pound) extinguisher was assessed by discharging Halon 1211, perfluorohexane, and Halotron I over a linear array of fire pans. A schematic diagram of the throw-range test setup is given in Figure 1. The eleven, 11-inch diameter fire pans were spaced 36 inches from center-to-center (Figure 2). Each pan contained 1/4 inch of fuel floating on 3 inches of water. Thirty seconds after the last pan was ignited, the agent was discharged from a fixed nozzle located 21 feet from the first pan. The nozzle was positioned 32 inches above and parallel with the ground (Figure 3). Extinguishers were allowed to fully discharge. The test objective was to establish the maximum effective throw-range for each candidate agent.

C. DRY-POOL FIRE EXTINGUISHMENT TESTS

Pool fire extinguishment tests are usually conducted by floating the fuel on a "pool" of water. These tests are not representative of most small fuel spills. A more common scenario is the spill of fuel on a dry, level concrete surface. To simulate this event, JP-4 fuel was poured onto a flat concrete surface, and ignited (dry-pool fire test). Fuel was poured onto the slab using a hose. The flow of fuel was terminated when the "fuel spill" covered the desired area (in ft²). Fuel spill area was varied between 250 and 800 ft². The approximate quantities of fuel required to cover a given concrete surface area were found to vary as shown in Table 2. As soon as the complete spill area was involved in the fire, the fire was extinguished by an experienced firefighter using a 150-pound Amerex extinguisher. The objective of the dry-pool fire test was to extinguish the fire as quickly as possible.

D. THREE-DIMENSIONAL INCLINED-PLANE TESTS

A fire scenario common to many aircraft accidents involves the flow of fuel from ruptured fuel tanks over sloping terrain or down an incline. The test apparatus constructed to simulate this condition was a 20-foot long, 5-foot wide steel ramp with a catch basin at the base which measures 4 feet by 8 feet (Figure 4). The ramp has a slope of 8.3 percent (1 inch per foot). To more accurately represent actual field conditions, the steel ramp was over-laid with 1.5 inches of concrete. JP-4 was discharged at a rate of 3 gpm (gallons per minute) through five holes in the

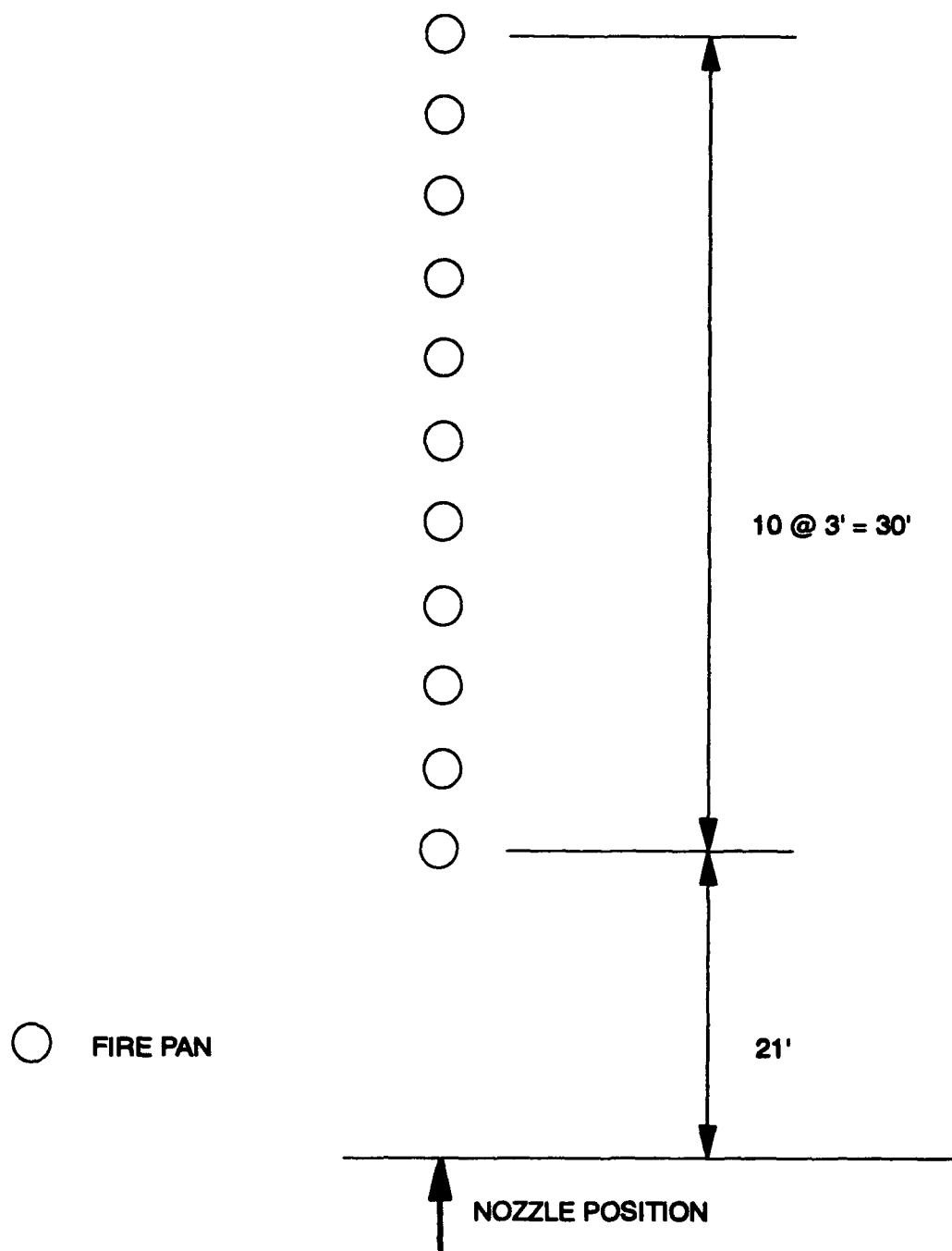


Figure 1. Agent Throw-Range Test Setup.

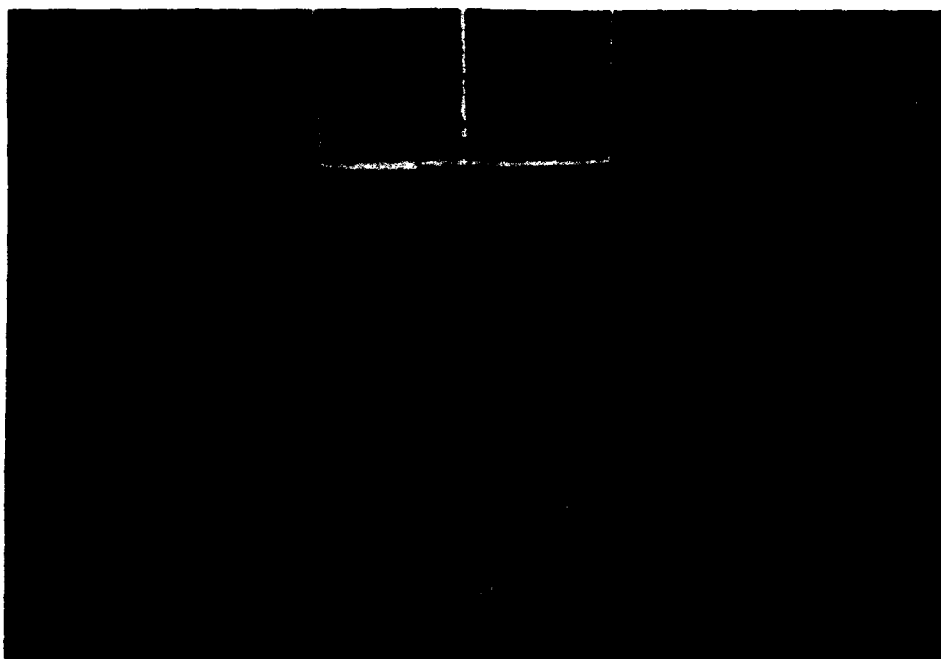


Figure 2. Fire Pan Array.

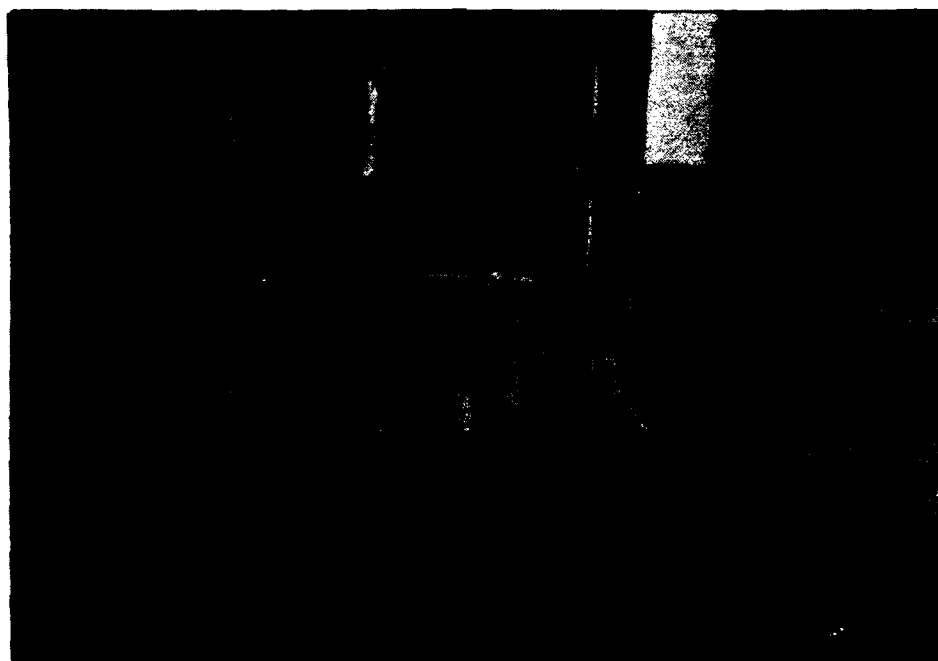


Figure 3. Extinguisher Nozzle Mount.

TABLE 2. FUEL REQUIRED TO PRODUCE A GIVEN "FUEL SPILL"

"Fuel Spill" Area (ft²)	Fuel Required (gallons)
250	7
400	11
800	15

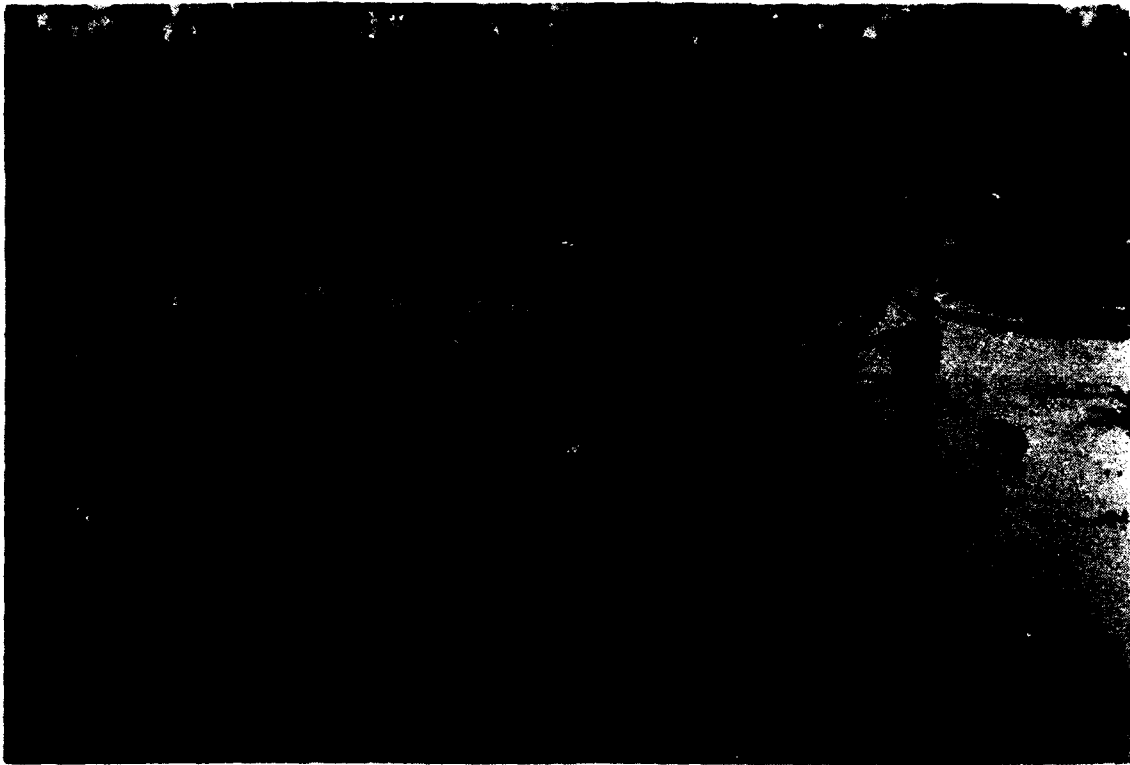


Figure 4. Inclined-Plane Running-Fuel Fire Test Device.

horizontal pipe positioned across the top of the incline. Once 1/4 inch (5 gallons) of fuel had accumulated in the catch pan, the fire was ignited. Following a 30-second preburn, the fire was extinguished using a 150-pound extinguisher. The firefighting approach employed on these fires was to extinguish the catch basin, then drive the fire up the ramp toward the fuel spray bar. The firefighter was positioned on the windward side of the ramp. The test objective was to extinguish the fire as rapidly as possible.

E. SIMULATED ENGINE-NACELLE RUNNING-FUEL FIRE TESTS

This test was designed to demonstrate the agent penetration and extinguishment capability for a full-size F-100 jet engine mockup apparatus (Figures 5 - 7) where fuel flows externally from the engine-nacelle cavity and onto the concrete pavement below. The low elevation (afterburner) end of the 189 ft³ engine-nacelle test apparatus (Figure 8) was unblocked to permit fuel to flow out of the end of the nacelle and onto the concrete pavement. A 5-gpm fuel flow was initiated from the nacelle afterburner fuel nozzle. Twenty-four gallons of JP-4 was allowed to flow through the nacelle and onto the concrete test pad. Following a 15-second preburn, the fire was attacked using a 150-pound extinguisher. The test objective was to extinguish the fire as rapidly as possible. A less severe nacelle test with 15 gallons of fuel on the concrete pad was also conducted.

F. SIMULATED WHEEL-WELL FIRE INVOLVING HYDRAULIC FLUID

This test was designed to simulate a wheel-well hydraulic fluid fire ignited by a hot brake. The test apparatus consisted of an F-4 aircraft tire and magnesium rim on a stand inside a 4-ft by 4-ft steel pan (Figure 9). A 2-gallon charge of hydraulic fluid was placed inside the pan. After an additional 1 gallon of hydraulic fluid had been poured on the tire itself, the fire was ignited. The most flammable MILSPEC hydraulic fluid specified for aircraft systems was used (MIL-H-5606F). Following a 90-second preburn, the fire was attacked using a 150-pound extinguisher. Using proper technique for this situation, the firefighter approached the wheel from a direction perpendicular to the axle. As an additional safety precaution, the aircraft tire was deflated prior to testing. It should be noted that the 90-second preburn was not sufficient to ignite either the rubber tire or the magnesium rim. The test objective was to extinguish the fire as rapidly as possible.

G. DATA COLLECTION

Two video cameras were used to record all test activities. Dozens of still photographs were taken to record significant events. All pertinent test data was recorded on test data collection sheets. Standard weather data, including: wind direction and velocity, temperature, and relative humidity, were recorded for each test.

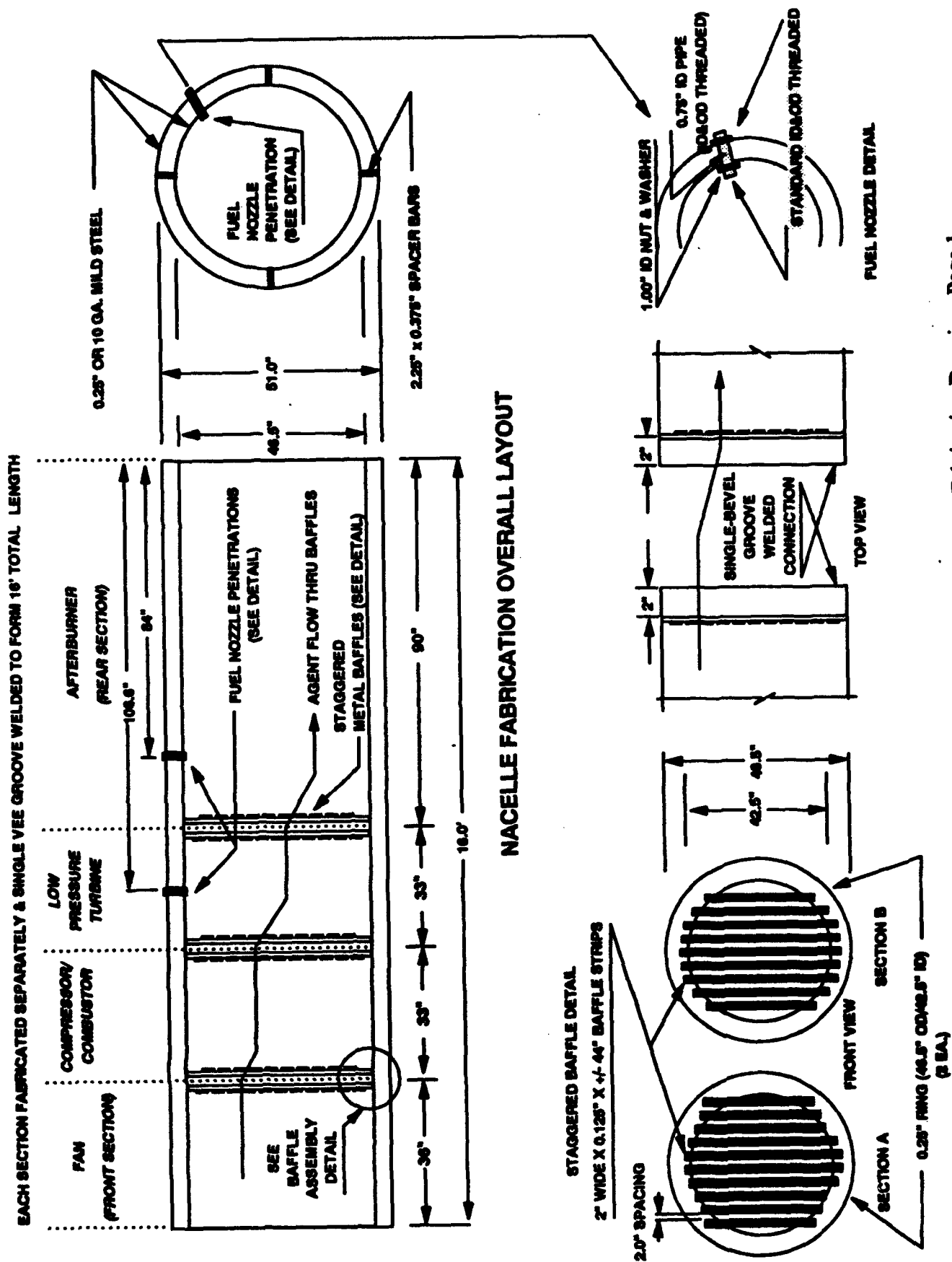


Figure 5. F-100 Engine-Nacelle Test Apparatus; Fabrication Drawing, Page 1.

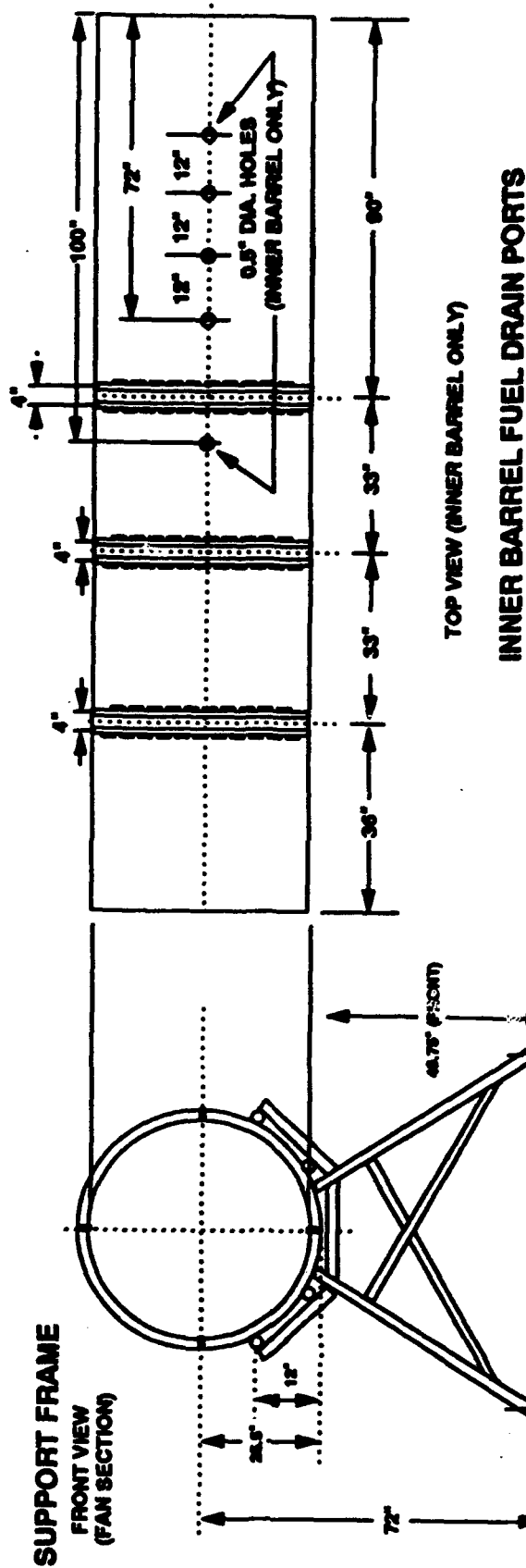
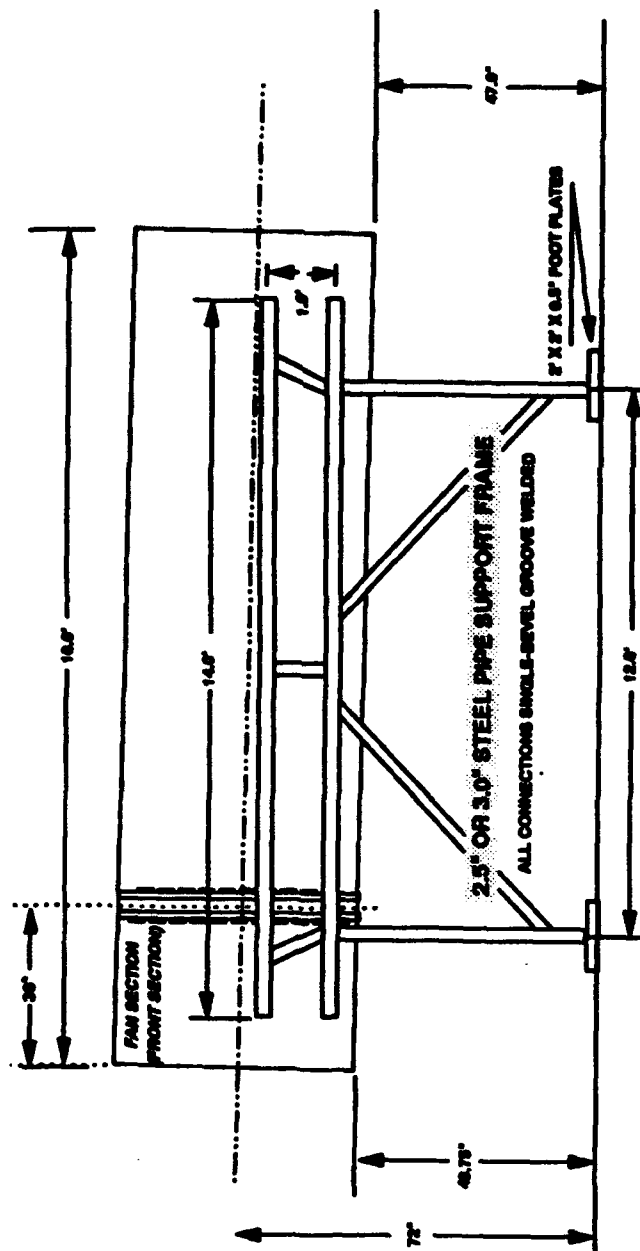
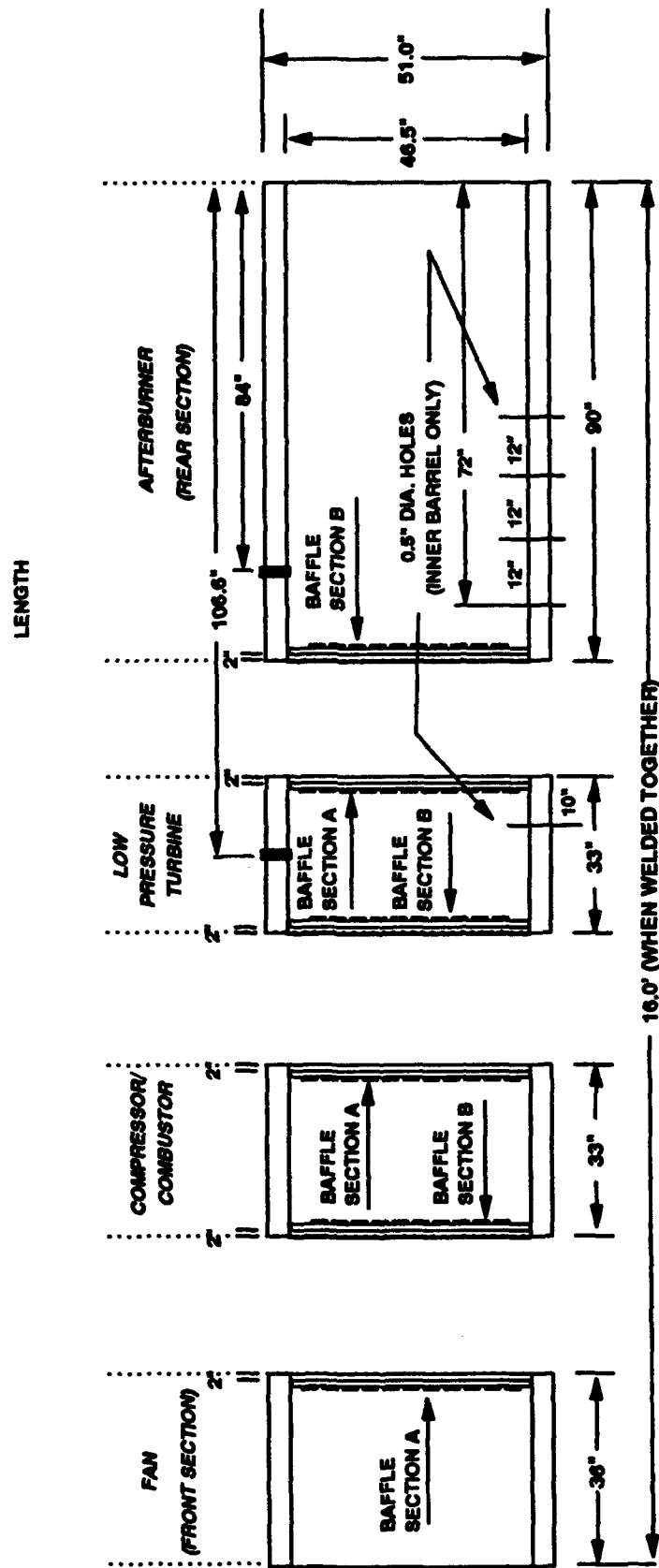


Figure 6. F-100 Engine-Nacelle Test Apparatus; Fabrication Drawing, Page 2.

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Figure 7. F-100 Engine-Nacelle Test Apparatus; Fabrication Drawing, Page 3.



Figure 8. Engine-Nacelle Test Apparatus.



Figure 9. Wheel-Well Fire Test Apparatus.

SECTION III

TEST RESULTS

A. INTRODUCTION

The dry-pool fire tests, inclined-plane running-fuel fire tests, engine-nacelle running-fuel fire tests, and wheel-well fire tests, were conducted at the WL/FIVCF environmentally-safe Large Scale Fire Research Facility, located at Tyndall AFB, Florida. To eliminate wind as a test variable, the agent throw-range tests were conducted inside the 84-foot long, 77-foot wide, Controlled Environment Burn Facility (CEBF), located at Tyndall AFB. All tests were accomplished by experienced firefighters.

The initial dry-pool, inclined-plane, engine-nacelle, and wheel-well fire test series was conducted from 24 to 26 March 1993. The throw-range tests were conducted on 21 and 22 April 1993. During the March and April testing, all three agents (Halon 1211, perfluorohexane, and Halotron I) were dispensed using standard Amerex Model 600, 150-pound fire extinguishers. The initial extinguisher operating pressure was 200 psi for Halon 1211 and perfluorohexane, and 240 psi for Halotron I. Halon 1211 and perfluorohexane were discharged through a standard 0.375-inch (9.5-mm) diameter orifice Halon nozzle. Halotron I was discharged using a 14-mm orifice nozzle provided by American Pacific Corporation.

Early in the March testing, it became apparent that a standard Amerex extinguisher was not the optimum system for dispensing Halotron I. Despite following precise extinguisher loading procedures, a smooth, continuous flow of agent could not be achieved throughout the entire duration of discharge. As the 14-mm nozzle was opened, the Halotron I exited the extinguisher in a smooth continuous stream. However, approximately 15-18 seconds after opening the nozzle, the smooth flow of agent became more of a pulsating action. (Complete extinguisher discharge requires approximately 40 seconds.) This pulsating discharge is referred to as "chugging." As the chugging increases, the agent flow rate decreases. This is undesirable since the firefighter can not apply agent to the fire at a constant rate.

Personnel from WL/FIVCF, the FAA, and AMPAC, concluded that the pulsating discharge was due mainly to the drop in extinguisher pressure during discharge. It was postulated, that agent performance would be improved if a constant agent discharge rate could be achieved. With this goal in mind, AMPAC designed a modification to the Amerex Model 600 extinguisher. A photograph of a modified extinguisher is shown in Figure 10. Specifically, the modification consisted of adding the following hardware to the Model 600 extinguisher:

- 7.7-liter DOT 3AA2015 booster cylinder with a standard CGA 580 valve (pressurized to 1200 psig).
- Bracket to support the booster cylinder.
- Single stage, diaphragm/spring regulator (6000 psi rated) with a minimum rated output pressure of 250 psig, and a 70 scfm air flow rate.
- 1/2-inch spring loaded poppet check valve, with a 1 psi cracking pressure, and a flow rate of 80 scfm at 1200 psig.
- 1/2-inch diameter, 2-foot long, 1450 psi rated, stainless steel braided Teflon® hose, with 1/2-inch swivel JIC connections.

- 18-inch long, 3/4-inch thick, 2-inch wide, 18-pound, carbon steel counterbalance weight, with "U" bolt connections.
- 11.5-mm diameter orifice nozzle.

The modified Amerex Model 600 extinguisher operated as follows: The extinguisher was filled with Halotron I base material and pressurized to 200 psi with Halotron I expander gas. The 7.7-liter booster cylinder was filled to 1200 psi with expander gas. The regulator on the booster cylinder was set to 200 psi outlet pressure. As agent was dispensed from the extinguisher, expander gas from the booster cylinder emptied into the main extinguisher vessel, reducing the pressure drop, and thereby eliminating the chugging experienced previously. The resulting agent discharge rate was increased 28 percent over the standard Amerex extinguisher (discharge rate increased from 3.6 lbs/sec to 4.6 lbs/sec). An additional benefit of having an external cylinder of expander gas was the ability to increase the agent capacity of the extinguisher system. Without the external expander gas cylinder, the agent capacity of the Amerex extinguisher was limited to 130 pounds. With the add-on expander gas cylinder, agent capacity was increased to 150 pounds.

To quantify the performance of Halotron I using the modified Amerex extinguisher, three fire extinguishment tests were repeated: engine-nacelle running-fuel fires, inclined-plane running-fuel fires, and dry-pool fires. These additional tests were conducted from 14 to 16 June 1993, using basically the same protocol described in Section II. Engine-nacelle running-fuel fires were conducted with 5, 10, and 15 gallons of fuel on the concrete pad. Twenty-five gallon fuel spills were used for the dry-pool fire tests. The inclined-plane running-fuel fires were conducted as described in Section II.

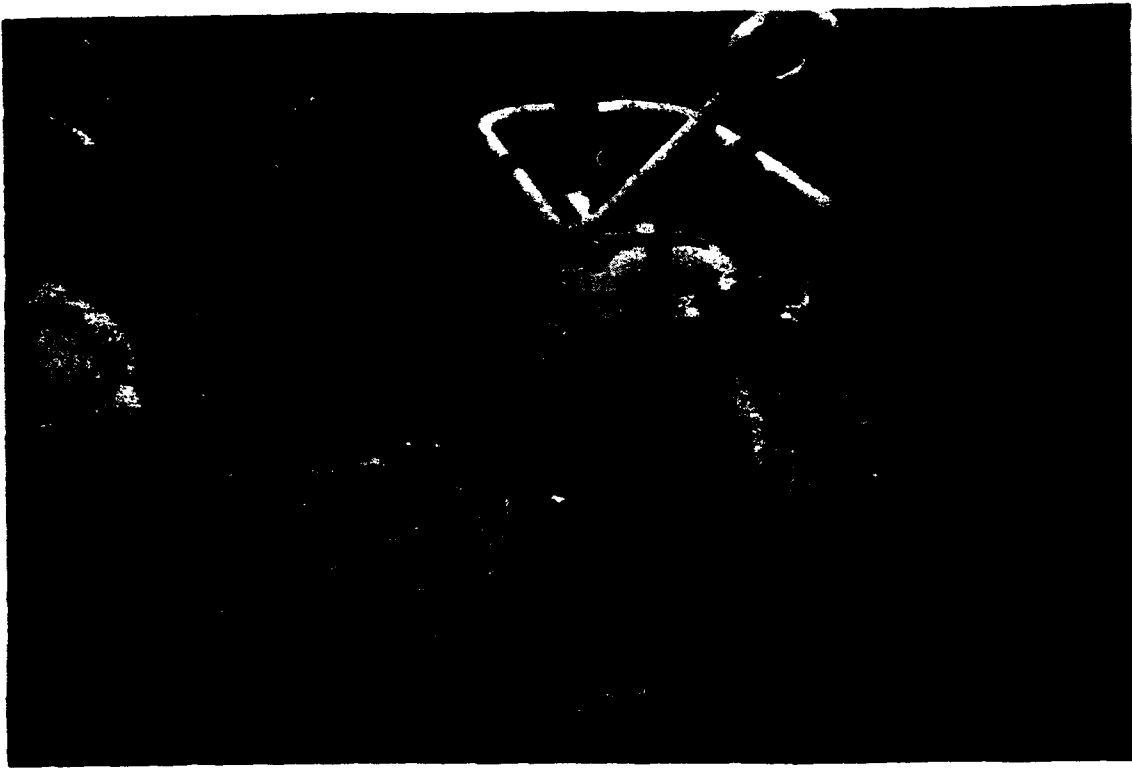


Figure 10. Modified Amerex Model 600 Extinguisher.

Following the June testing, AMPAC contracted with Amerex Corporation, to optimize the modified extinguisher system which had just been tested. A photograph of the resulting optimized extinguisher is shown in Figure 11. Specifically, the optimization consisted of adding the following hardware to the standard Amerex Model 600 extinguisher:

- 10.6-liter DOT 3AA2015 cylinder with std. CGA 580 valve with quick open option (pressurized to 2000 psig).
- Brackets to support booster cylinder.
- Single stage diaphragm/spring regulator (3000 psi rated) rated at 183 scfm at 2015 psig supply side, 230 psig delivery side (regulator was set to 230 psig).
- Two, 16-inch x 3/16-inch high-pressure rubber hoses rated at 3000 psi.
- Two, 1/4-inch female NPT spring loaded poppet check valves with a 1 psi cracking pressure, and a flow rate of 80 scfm at 230 psig.
- A pneumatic operated valve actuated by 230 psi with a standard 3/4-inch hose connection.
- 3/4-inch x 1/4-inch reducer bushing for check valve connection from extinguisher.
- 14-mm orifice diameter nozzle (for use with 180 lb. charge).

Operation of the optimized extinguisher was conceptually the same as for the modified extinguisher discussed previously. The only differences were that the expander gas booster cylinder was pressurized to 2000 psi, and the regulator was set for 230 psi. The resulting agent discharge rate for this extinguisher system was 4.9 lbs/sec (a 36 percent increase over the standard Amerex Model 600). By further increasing the size and operating pressure of the booster cylinder, it was possible to increase the agent capacity of the extinguisher to 180 pounds.



Figure 11. Optimized Amerex Model 600 Extinguisher.

Halotron I testing, using the fully optimized Amerex Model 600 extinguisher system, was conducted from 28 October to 2 November 1993. Only dry-pool and engine-nacelle tests were conducted. Ten, 15, and 20 gallon JP-4 dry-pool fires were conducted. Engine-nacelle running-fuel fires were conducted with 5 and 10 gallons of fuel on the concrete pad.

Results of all testing conducted under this research program are summarized in the following sub-sections. Results are organized by test type (i.e., throw-range, dry-pool, inclined-plane, engine-nacelle, and wheel-well). All Halotron I test results are annotated with the description of the extinguisher configuration used (i.e., standard Amerex Model 600, modified Model 600 with a 1200 psi booster, optimized Model 600 with a 2000 psi booster).

B. AGENT THROW-RANGE TESTS

Each of the three fire-extinguishing agents tested in this program, contains at least one element of the halogen group (i.e., fluorine, chlorine, bromine). Thermal decomposition (combustion) of these firefighting agents results in the production of one or more of the highly toxic compounds: hydrogen fluoride (HF), hydrogen chloride (HCl), and hydrogen bromide (HBr). The presence of these compounds within the enclosed aircraft shelter results in a hostile environment. Therefore, (for safety) no observers were allowed inside the aircraft shelter during throw-range testing. Real-time test observation was accomplished by connecting the two video cameras located inside the shelter to TV monitors located outside the shelter. The only personnel inside the shelter during the tests were the two firefighters conducting the experiment. Each firefighter was equipped with a Self Contained Breathing Apparatus (SCBA) and dressed in a Firefighter Ensemble.

The throw-range test results are portrayed in Figures 12 - 14. These tests were conducted with standard Amerex Model 600 extinguishers. This test was conducted once each with Halon 1211, perfluorohexane, and Halotron I. Halon 1211 extinguished all 11 pans, while perfluorohexane extinguished only the first 7 pans, and Halotron I extinguished three pans.

In an attempt to investigate the effect of nozzle orientation on throw-range, tests were conducted with the nozzle tip elevated 1/4 inch (2.2 degrees) above horizontal, and lowered 1/4 inch (2.2 degrees) below horizontal. It was found that elevating the nozzle tip allowed perfluorohexane to extinguish one additional pan. The throw-range results for Halon 1211 and Halotron I were not effected by varying the nozzle orientation.

C. DRY-POOL FIRE EXTINGUISHMENT TESTS

The sequence of events for a typical dry-pool fire extinguishment test is shown in Figures 15 - 17. Figure 15 shows the creation of the "fuel spill". Figure 16 shows a fuel spill immediately after ignition. Figure 17 shows a firefighter extinguishing an 800 ft² dry-pool fire.

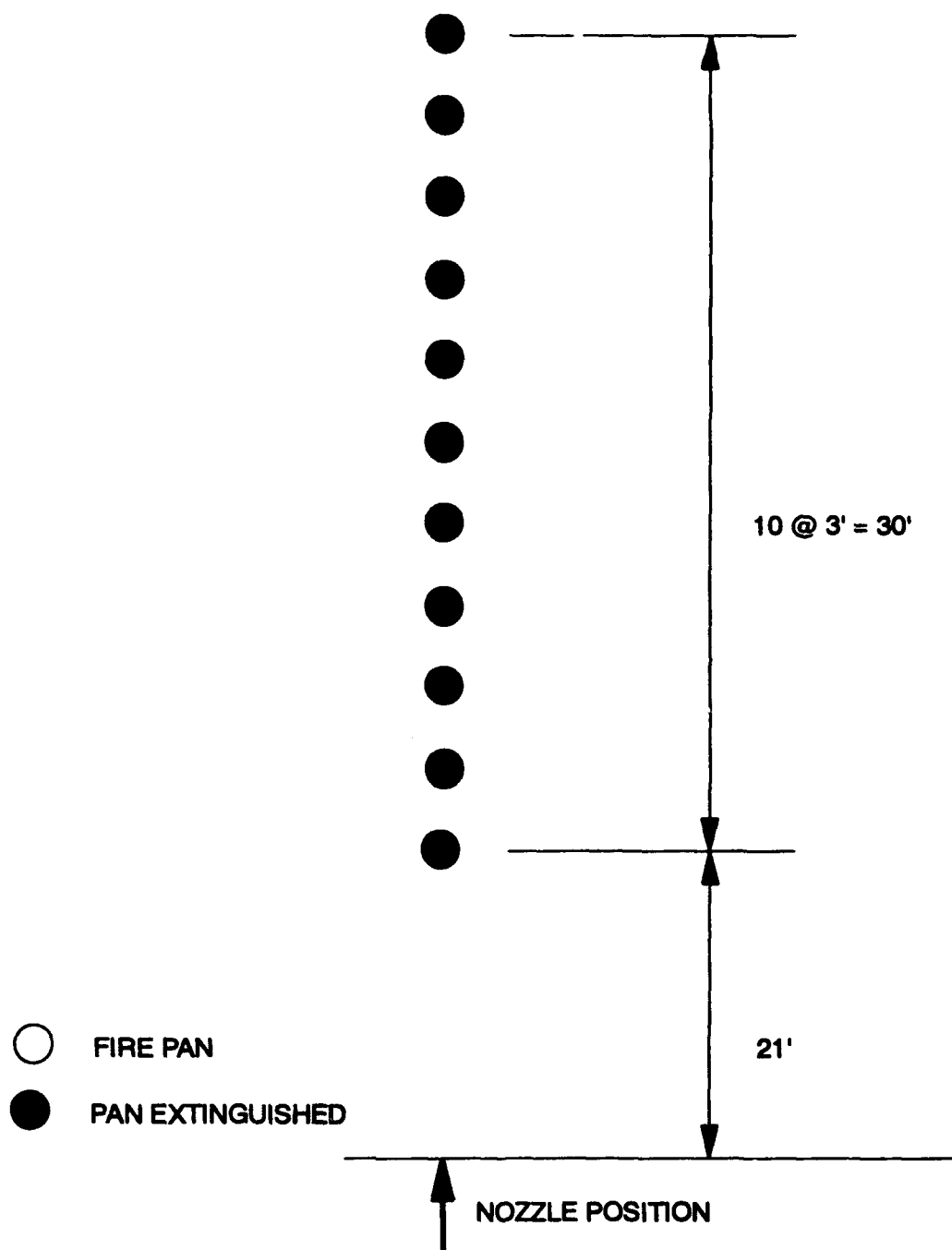


Figure 12. Halon 1211 Throw-Range Test Results.

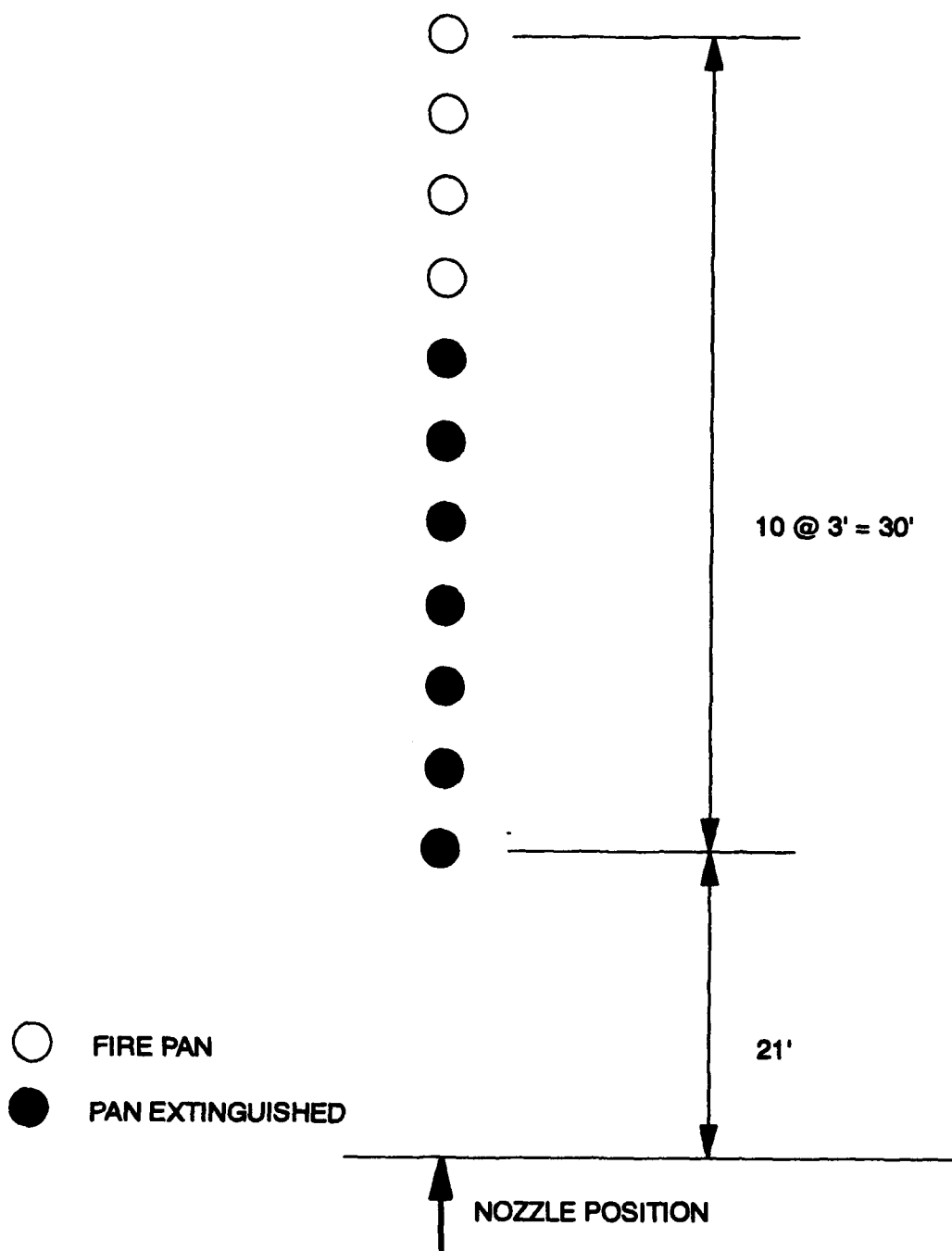


Figure 13. Perfluorohexane Throw-Range Test Results.

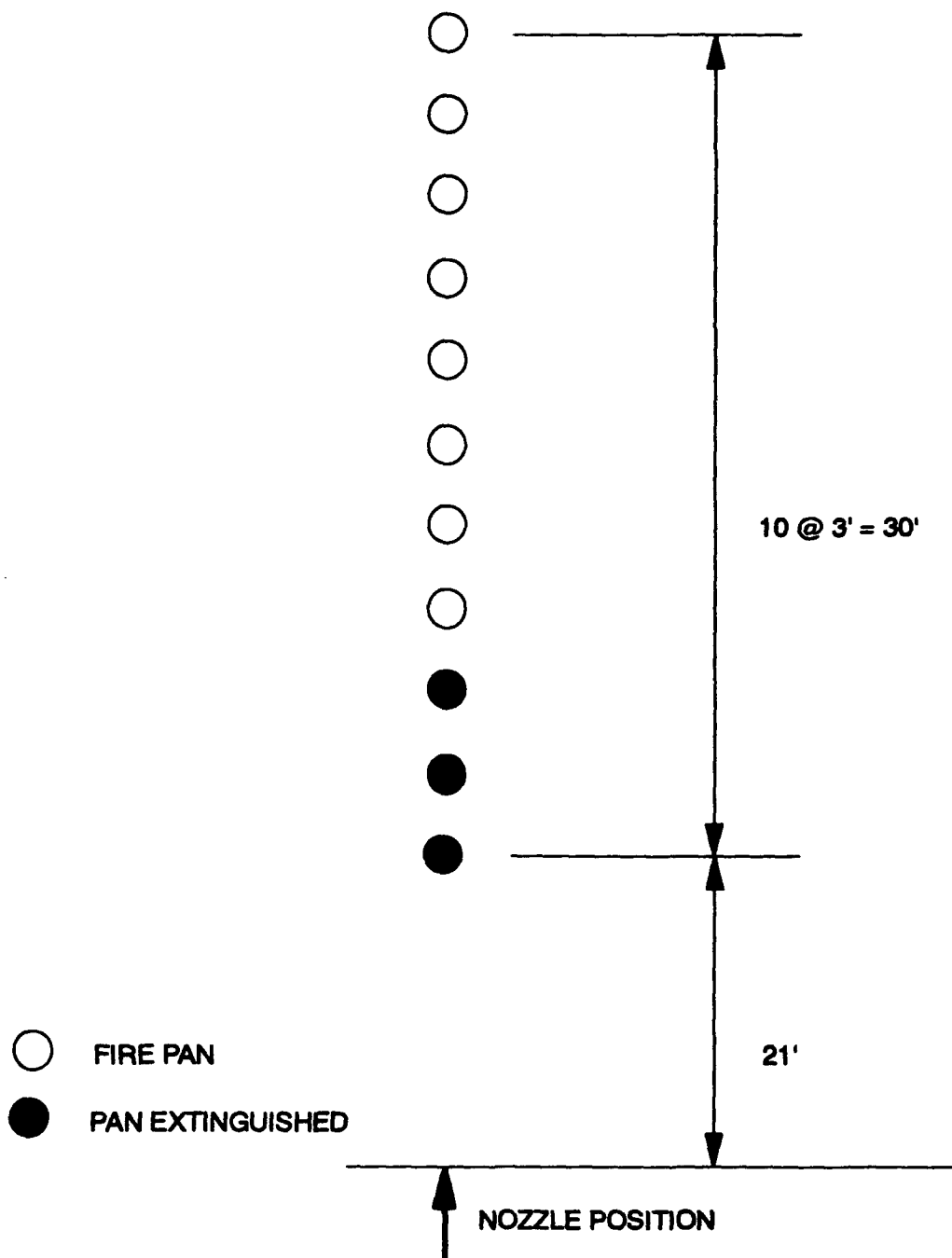


Figure 14. Halotron I Throw-Range Test Results.



Figure 15. Creating a Simulated "Fuel Spill".

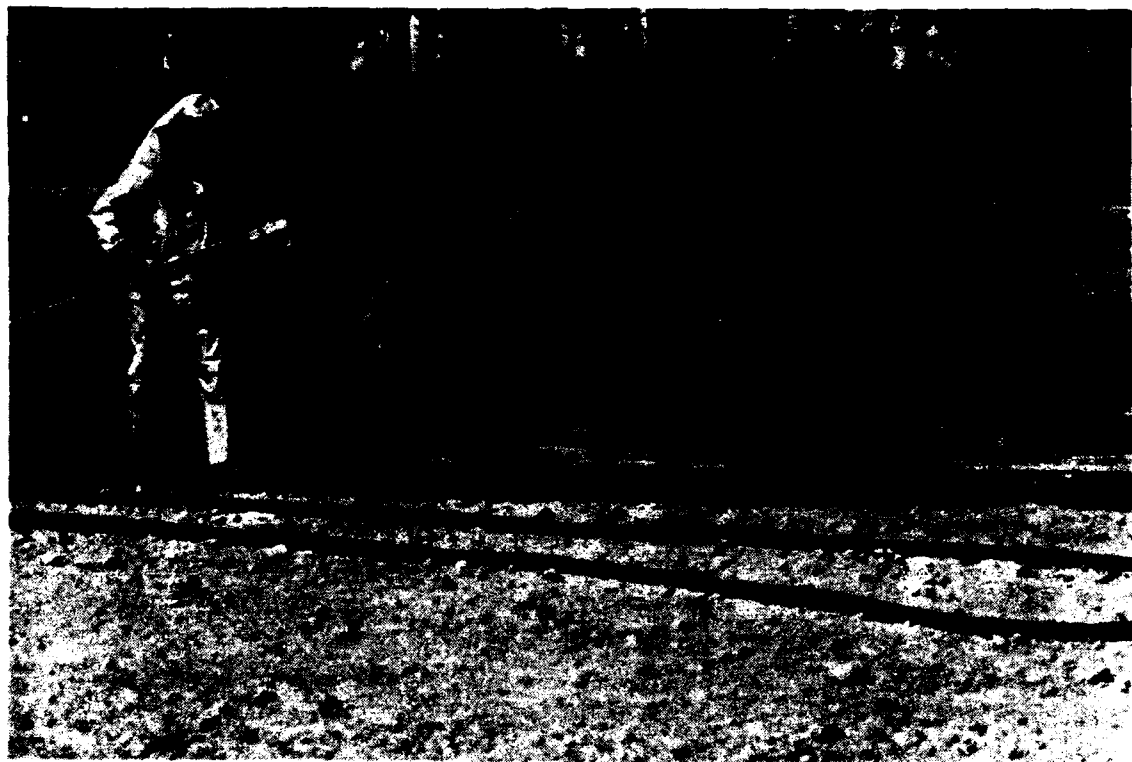


Figure 16. Fuel Spill Immediately After Ignition.



Figure 17. Firefighter Extinguishing a Dry-pool Fire.

Results of the dry-pool fire extinguishment tests are given in Table 3. Using standard Amerex extinguishers, Halotron I and perfluorohexane exhibited equal performance. Both agents were able to extinguish a 250-ft², a 400-ft², and an 800-ft² pool fire in a combined time of 36.5 seconds.

Subsequent Halotron I testing, using modified Amerex extinguishers, utilized fires based on a measured quantity of fuel (in gallons) as opposed to a "fuel spill" area (in ft²). As a result, it is difficult to make any quantitative comparisons to the previous results. However, it should be noted that a pair of 20-gallon dry-pool fires were successfully extinguished using an optimized Model 600 extinguisher with a 2000 psi booster.

D. THREE-DIMENSIONAL INCLINED-PLANE TESTS

A typical inclined-plane running-fuel fire test is illustrated in Figures 18 - 21. Figure 18 shows the inclined-plane with fuel flowing from the spray pipe at the top. Figure 19 shows the ramp after ignition of the fire. Figure 20 shows a firefighter chasing the fire up the ramp. Figure 21 shows the ramp after complete extinguishment of the fire.

Results of the inclined-plane running-fuel fire tests are given in Table 4. Using standard Amerex Model 600 extinguishers, Halotron I was nearly twice as effective as perfluorohexane in extinguishing the inclined plane fires. In the three Halotron I tests, the fires were extinguished in an average of 17.7 seconds. For the three perfluorohexane tests, the average extinguishment time was 34.7 seconds.

TABLE 3. DRY-POOL FIRE RESULTS

Agent	"Fuel Spill" (ft ²)	Extinguishment Time (sec)
Halon 1211	250	4
	800	13
perfluorohexane	250	5.5
	400	13
	800	18
Halotron I ^(a)	250	6.5
	400	8
	800	22
Halotron I ^(b)	25 gal	DNE
	25 gal	DNE
Halotron I ^(c)	10 gal	27
	15 gal	DNE
	20 gal	30
	20 gal	20
<p>(a) standard Amerex Model 600</p> <p>(b) Amerex Model 600 with 1200 psi booster</p> <p>(c) Amerex Model 600 with 2000 psi booster</p> <p>DNE: Did not extinguish</p>		

E. SIMULATED ENGINE-NACELLE RUNNING-FUEL FIRE TESTS

A typical engine-nacelle running-fuel fire test is shown pictorially in Figures 22 and 23. Figure 22 shows fuel running out of the nacelle onto the concrete slab. Figure 23 shows the fire being attacked with a 150-pound extinguisher.

Results of the engine-nacelle running-fuel fire tests are given in Tables 5. Only 24-gallon and 15-gallon fire tests were conducted using standard Model 600 extinguishers. Neither Halotron I or perfluorohexane was capable of extinguishing these fires.

Using "boosted" Amerex extinguishers, Halotron I consistently extinguished the engine-nacelle fires with 5 gallons of fuel on the concrete pad. Ten-gallon nacelle fires were extinguished approximately one-third of the time, using the modified extinguishers.

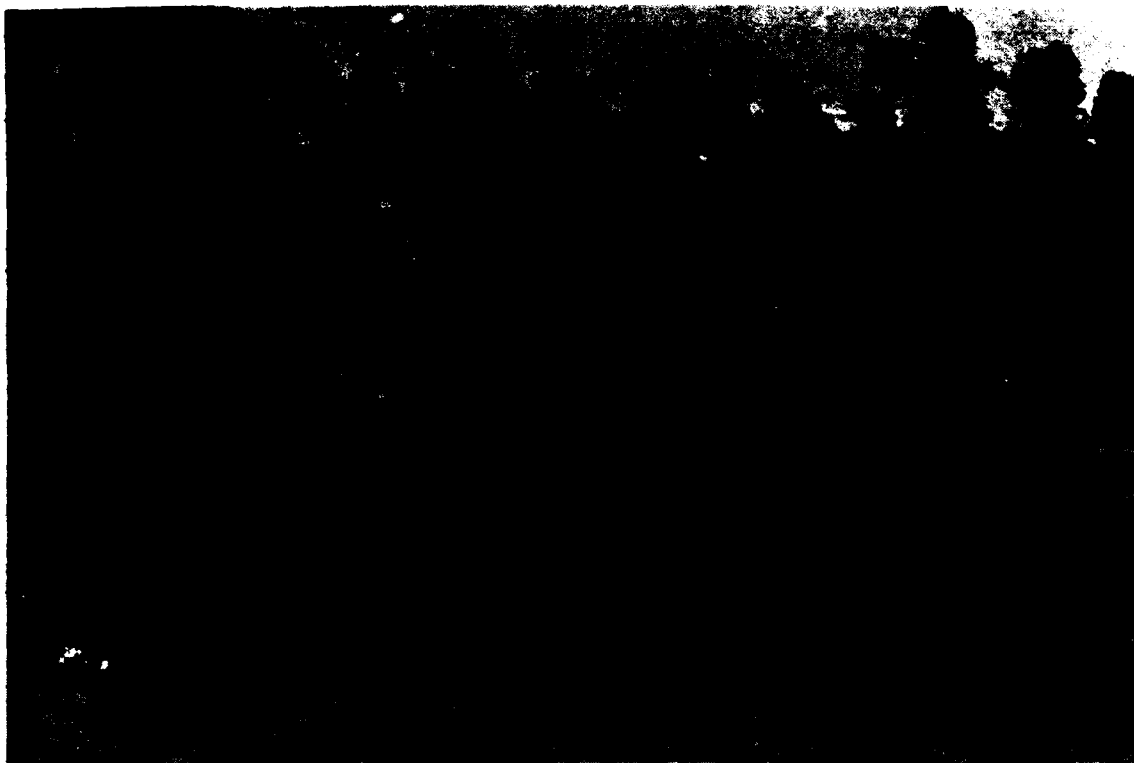


Figure 18. Inclined-Plane with Fuel Flowing.



Figure 19. Ramp After Fire Ignition.



Figure 20. Firefighter Chasing Fire Up Ramp.



Figure 21. Ramp After Complete Fire Extinguishment.

TABLE 4. THREE-DIMENSIONAL INCLINED-PLANE TEST RESULTS

Agent	Extinguishment Time (sec)
Halon 1211	23
perfluorohexane	28
	36
	40
Halotron I ^(a)	17
	13
	23
Halotron I ^(b)	DNE
	DNE
	17
	28
<p>^(a) standard Amerex Model 600</p> <p>^(b) Amerex Model 600 with 1200 psi booster</p> <p>DNE: Did not extinguish</p>	



Figure 22. Fuel Running Out of Nacelle Onto Slab.



Figure 23. Firefighter Attacking Engine-Nacelle Fire.

F. SIMULATED WHEEL-WELL FIRE INVOLVING HYDRAULIC FLUID

Figures 24 - 26 illustrate the process for conducting a wheel-well fire test. Figure 24 shows the hydraulic fluid being ignited. Figure 25 shows the burning aircraft tire at initial agent application. Figure 26 shows the aircraft tire when the fire is nearing extinguishment.

Results of the wheel-well fire tests are given in Table 6. This test was conducted once with each agent. Using standard Amerex Model 600 extinguishers, Halotron I was 50 percent more effective than perfluorohexane against this hydraulic fluid fire.

TABLE 5. ENGINE-NACELLE RUNNING-FUEL TEST RESULTS
(5 gpm flow rate)

Agent	Extinguishment Time (sec)
24 gallons JP-4 on pad	
Halon 1211	15
perfluorohexane	DNE
	DNE
Halotron I ^(a)	DNE
	DNE
15 gallons JP-4 on pad	
perfluorohexane	DNE
Halotron I ^(a)	DNE
Halotron I ^(b)	DNE
	DNE
10 gallons JP-4 on pad	
Halotron I ^(b)	DNE
	DNE
	26
Halotron I ^(c)	DNE
	DNE
	29
5 gallons JP-4 on pad	
Halotron I ^(b)	26
	37
Halotron I ^(c)	27
<p>^(a) standard Amerex Model 600</p> <p>^(b) Amerex Model 600 with 1200 psi booster</p> <p>^(c) Amerex Model 600 with 2000 psi booster</p> <p>DNE: Did not extinguish</p>	



Figure 24. Hydraulic Fluid Being Ignited.



Figure 25. Agent Being Applied to Burning Aircraft Tire.

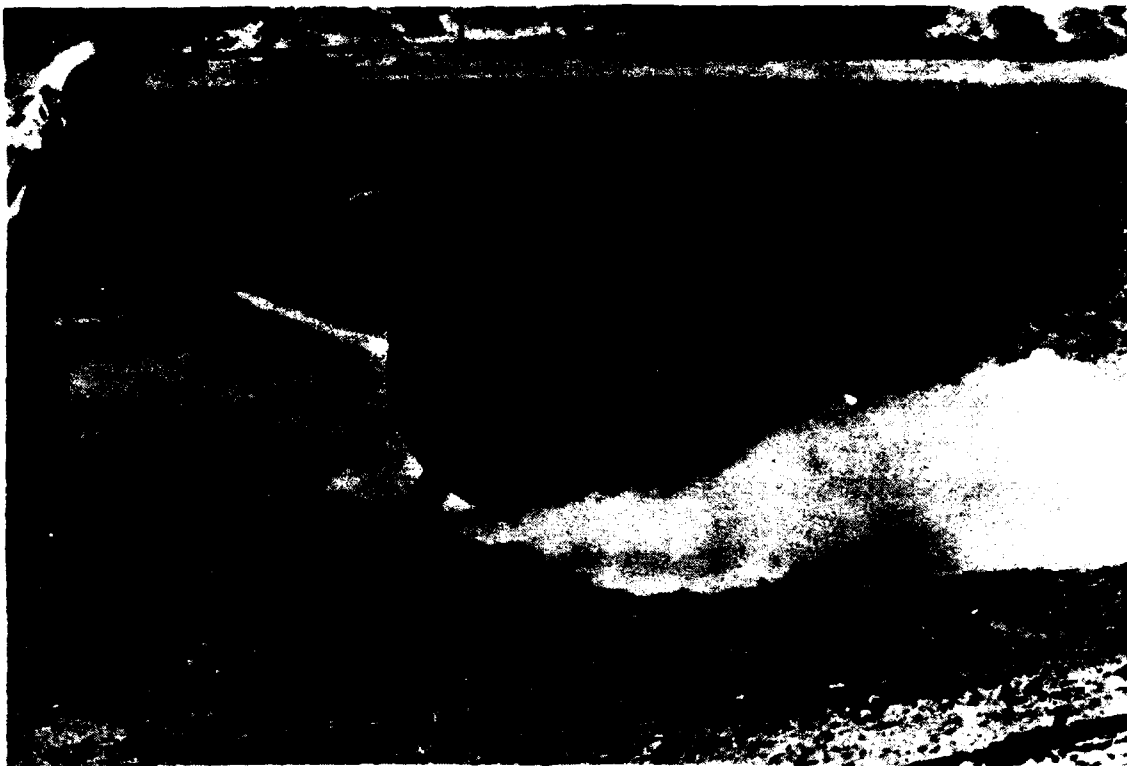


Figure 26. Tire Fire Nearing Extinguishment.

TABLE 6. WHEEL-WELL FIRE TEST RESULTS

Agent	Extinguishment Time (sec)
Halon 1211	5
perfluorohexane	18
Halotron I ^(a)	12
^(a) standard Amerex Model 600	

SECTION IV

CONCLUSIONS

When using standard Amerex Model 600 extinguishers to dispense each agent, Halotron I proved to be slightly more effective than perfluorohexane for extinguishing the five fire scenarios tested during this project. Halotron I was nearly twice as effective as perfluorohexane for extinguishing the inclined-plane running-fuel fires; and 50 percent more effective than perfluorohexane for extinguishing the wheel-well hydraulic fluid fires. Both agents exhibited equal performance on the dry-pool fires and the engine-nacelle running-fuel fires. Perfluorohexane outperformed Halotron I in the effective throw-range testing.

Performance of the Halotron I system was improved by optimizing the Amerex extinguisher with an expander gas booster cylinder. The magnitude of the improvement was not quantified since the optimized extinguisher was not tested against the original fire test scenarios. Using the optimized extinguisher, the "chugging" problem was eliminated, and the agent discharge rate was increased by 36 percent. Additionally, the throw-range was improved (based on visual observation), and the agent capacity of the extinguisher was increased from 130 pounds to 180 pounds.